Advancements in Regenerative Fuel Cell Technologies for Space Applications

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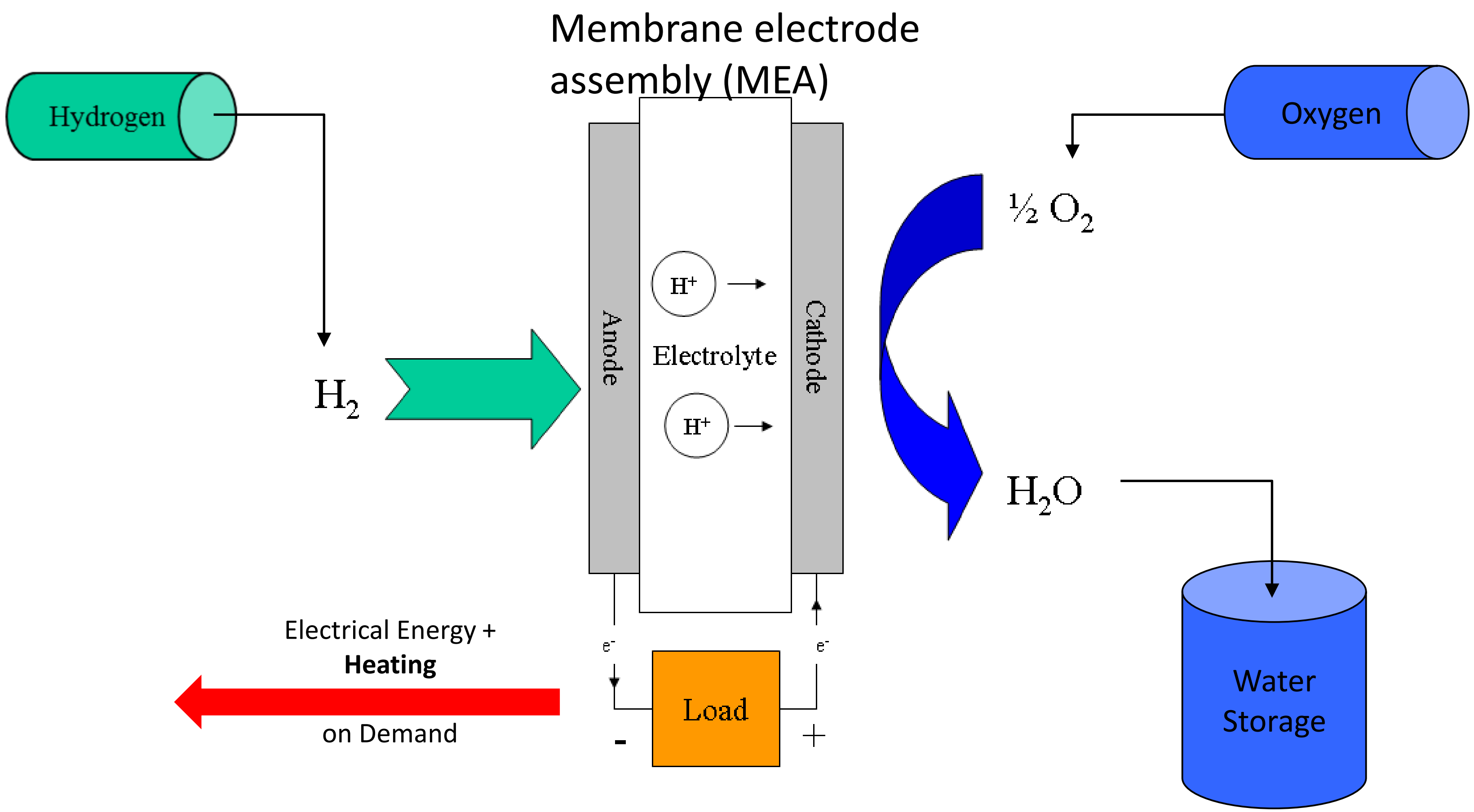
AAAS 99th Annual Meeting

Pomona CA

Outline

- The PEM fuel cell
- Regenerative fuel cell systems and space applications
- Performance improvements
- System design

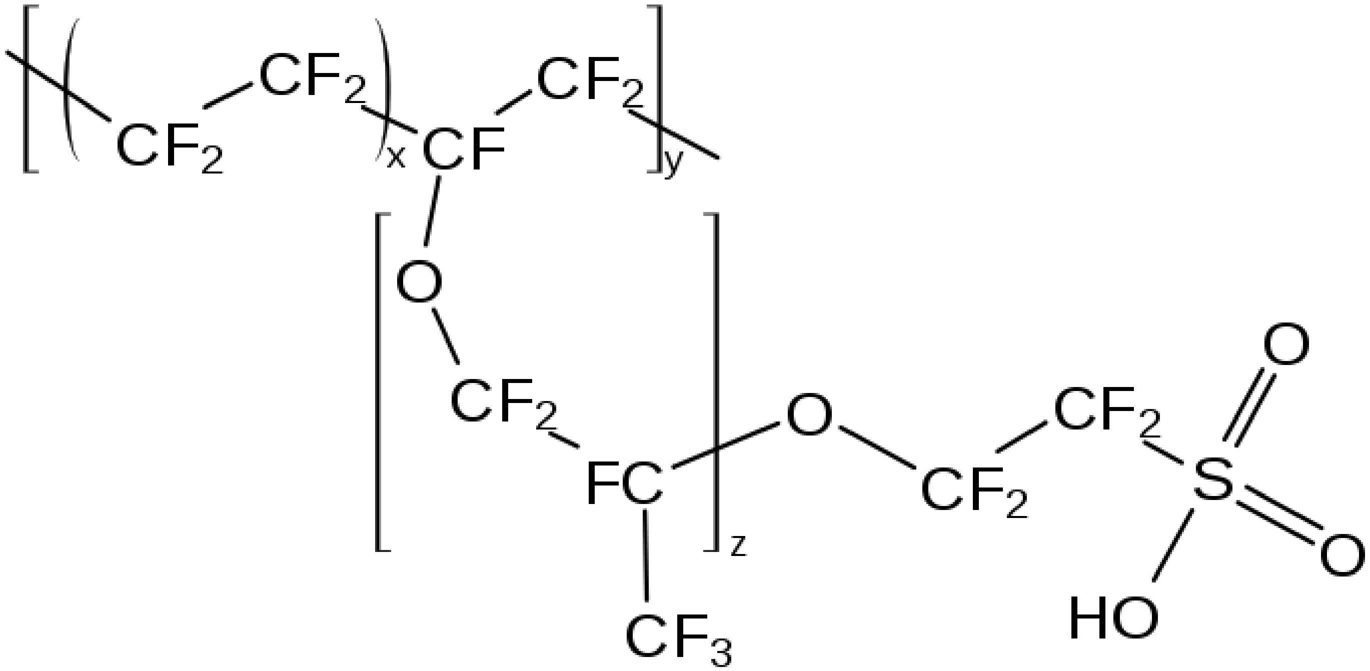
The PEM fuel cell



$H_2 + 1/2O_2 \rightarrow H_2O$ + Energy

E = 1.23 V per cell

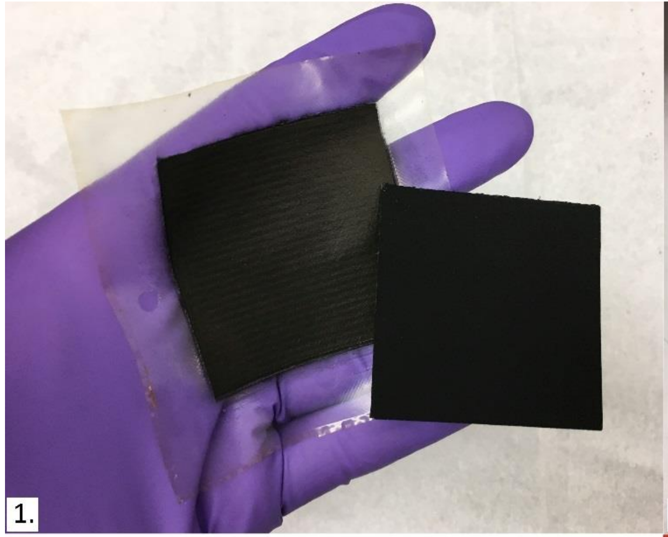
The Polymer Electrolyte

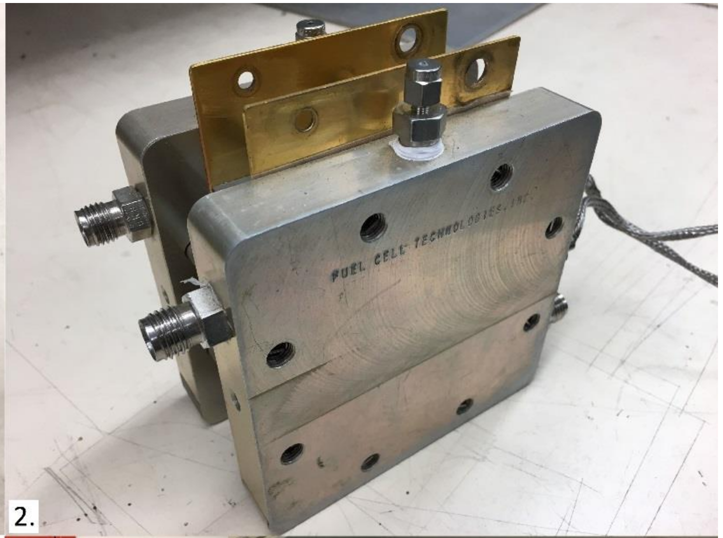


Nafion

- Superacidic
  pKa = -6
- Used in thin films (2-7 mils)

Fuel Cell Development

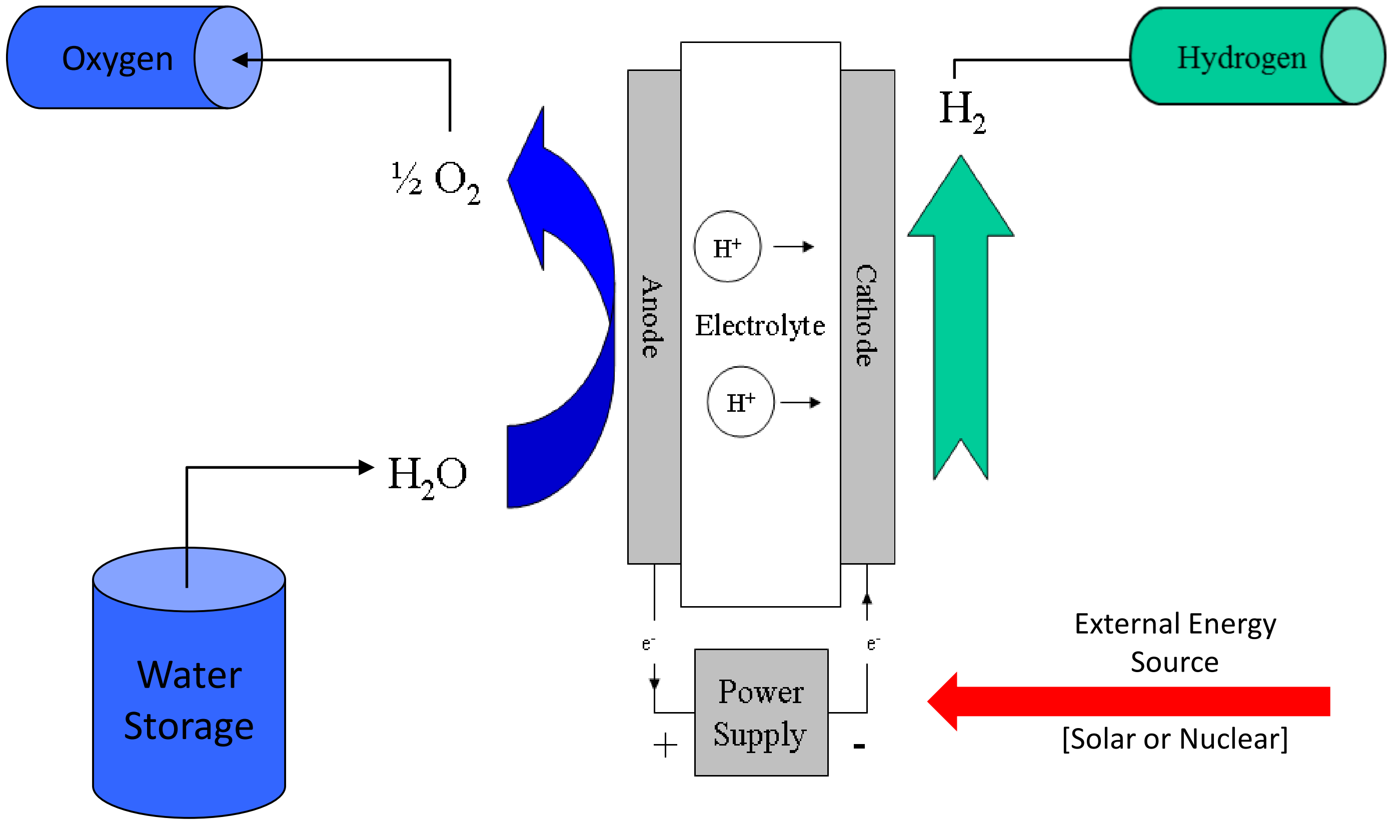




Clockwise:
1. JPL high performance fuel cell MEA. Gas diffusion layer is detached to expose catalyst layer beneath.
2. Single cell hardware for testing fuel cell MEAs.
3. Fuel cell test station in JPL's fuel cell lab

Government sponsorship acknowledged.

Water Electrolysis



Reverse fuel cell reaction

H_2O + Energy $\rightarrow H_2 + 1/2O_2$

High pressure operation ~ 3600psi

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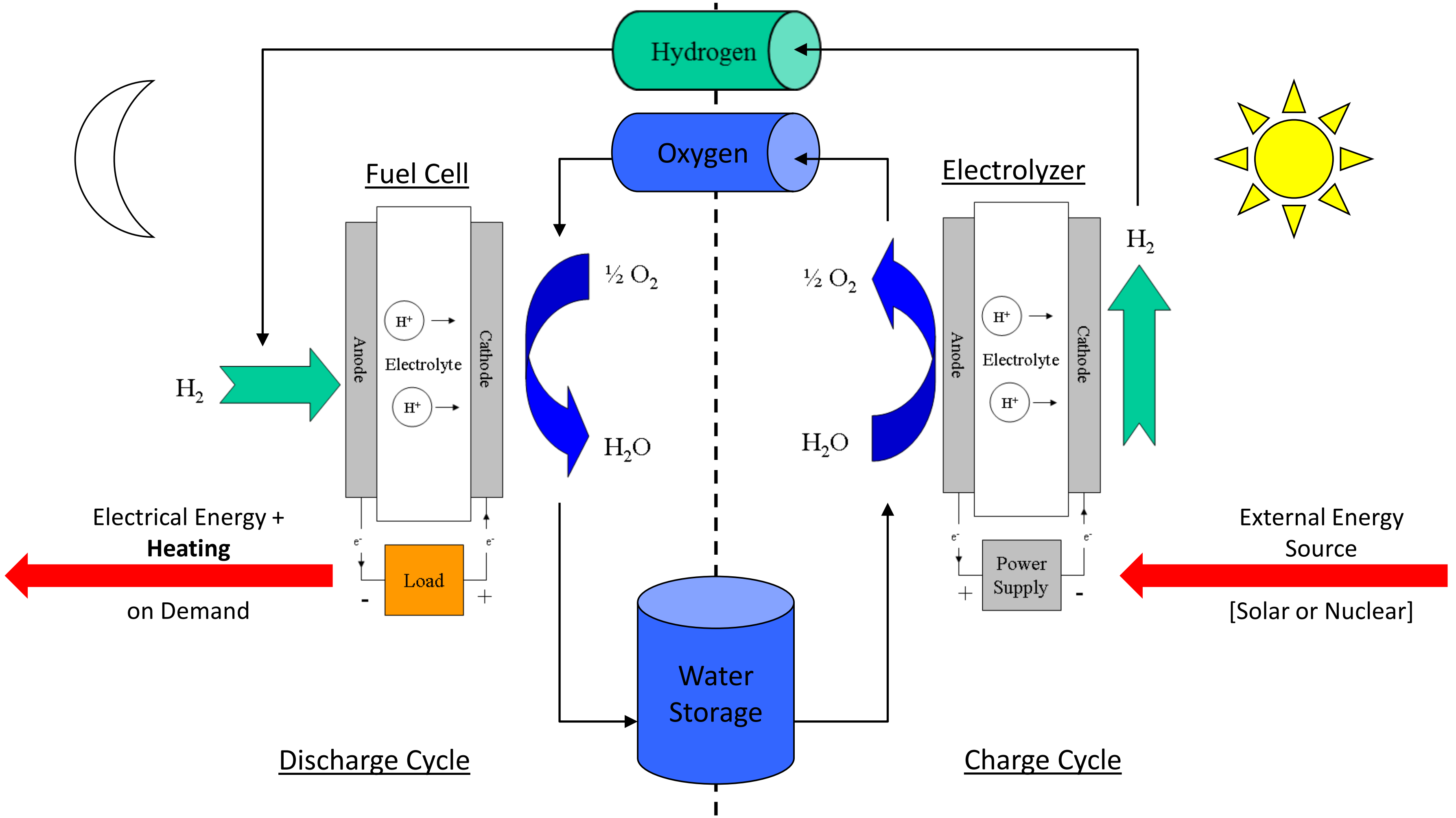
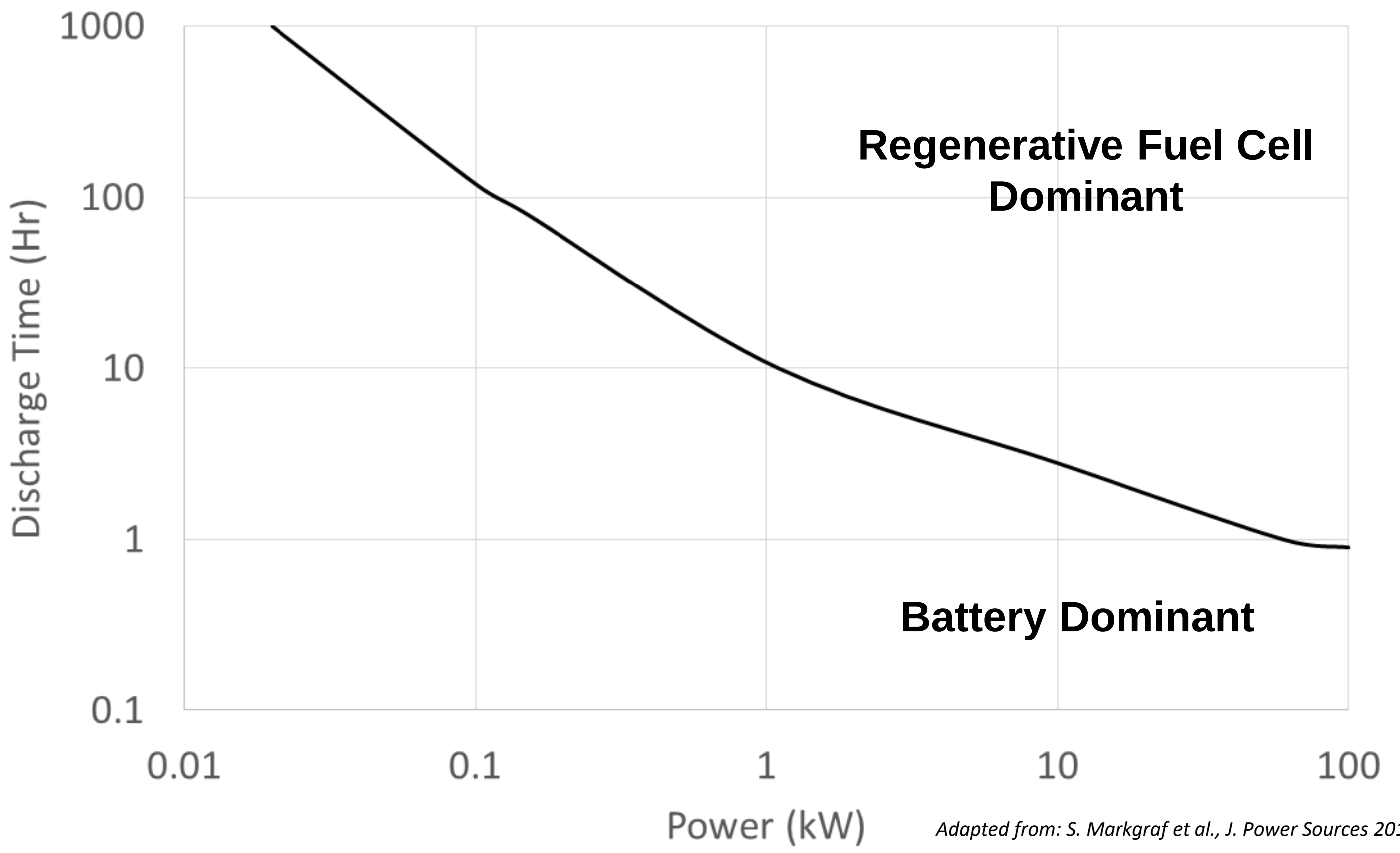
Regenerative Fuel Cell Concept



Space Applications

Mass-efficient energy storage for larger scale applications



Adapted from: S. Markgraf et al., J. Power Sources 201 (2012) 236-242

Regen fuel cells scale up well: higher specific mass for larger systems

Batteries scale up linearly: constant specific mass (Wh/kg)

Space Applications

Integration with life support systems

- “Waste” heat is not waste at all
- Emergency high pressue oxygen
- Emergency water

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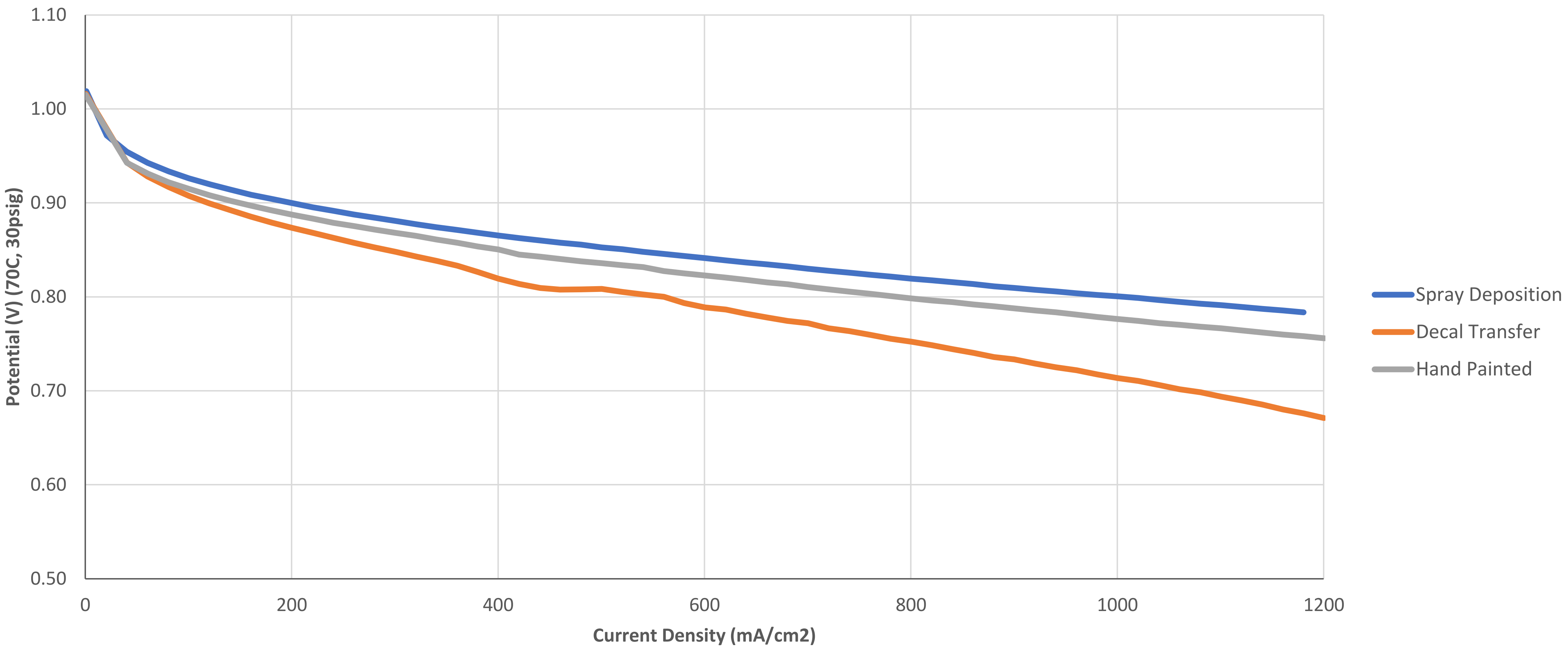
High Performance Regenerative Fuel Cell Concepts

- Fabrication methods
  - Electrode structure
  - Intimacy of electrode contact with membrane
- Water rejection
  - Electrode structure
  - Gas diffusion layer choice
- Membrane thickness
- High Pt catalyst loading
- Gas Diffusion Layer Optimization
- Oxygen evolution catalyst development for electrolysis

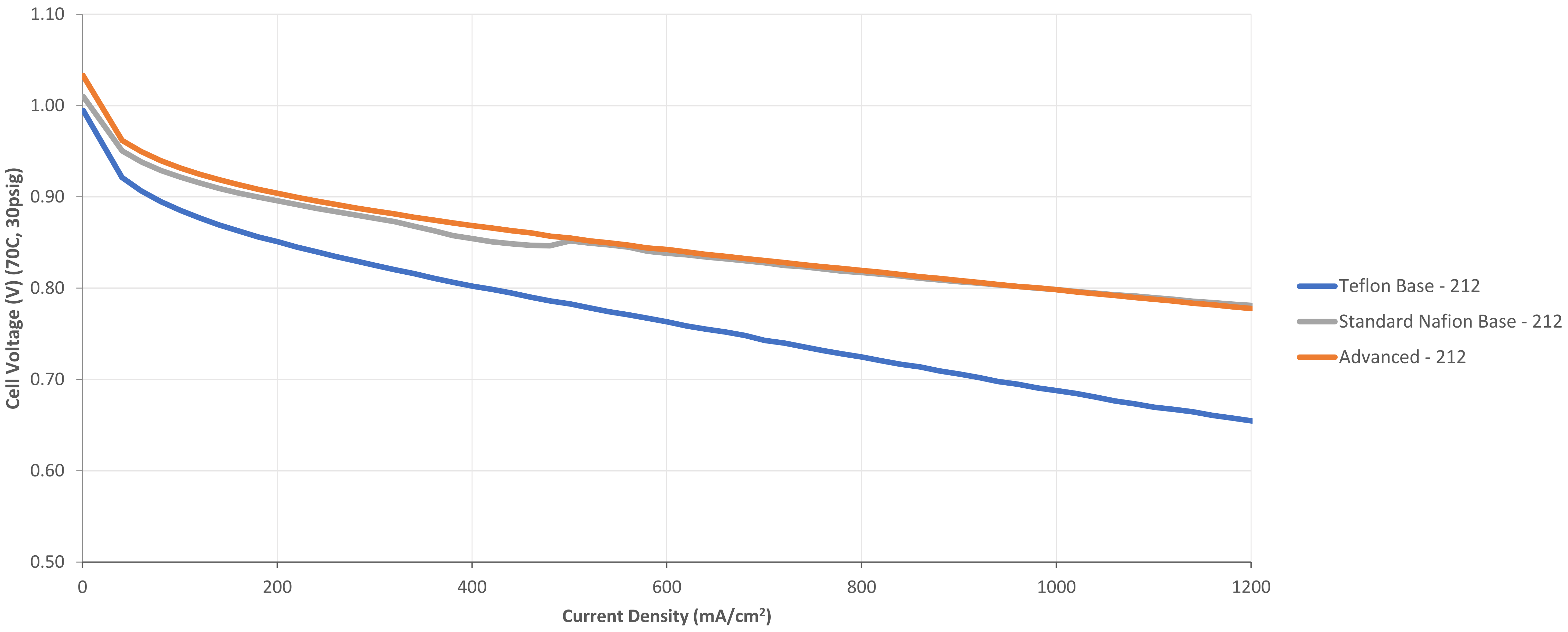
High Performance Fuel Cell Concepts

Fabrication Methods – fast drying spray deposition process



High Performance Fuel Cell Concepts

Water rejection – advanced Teflon electrode structure



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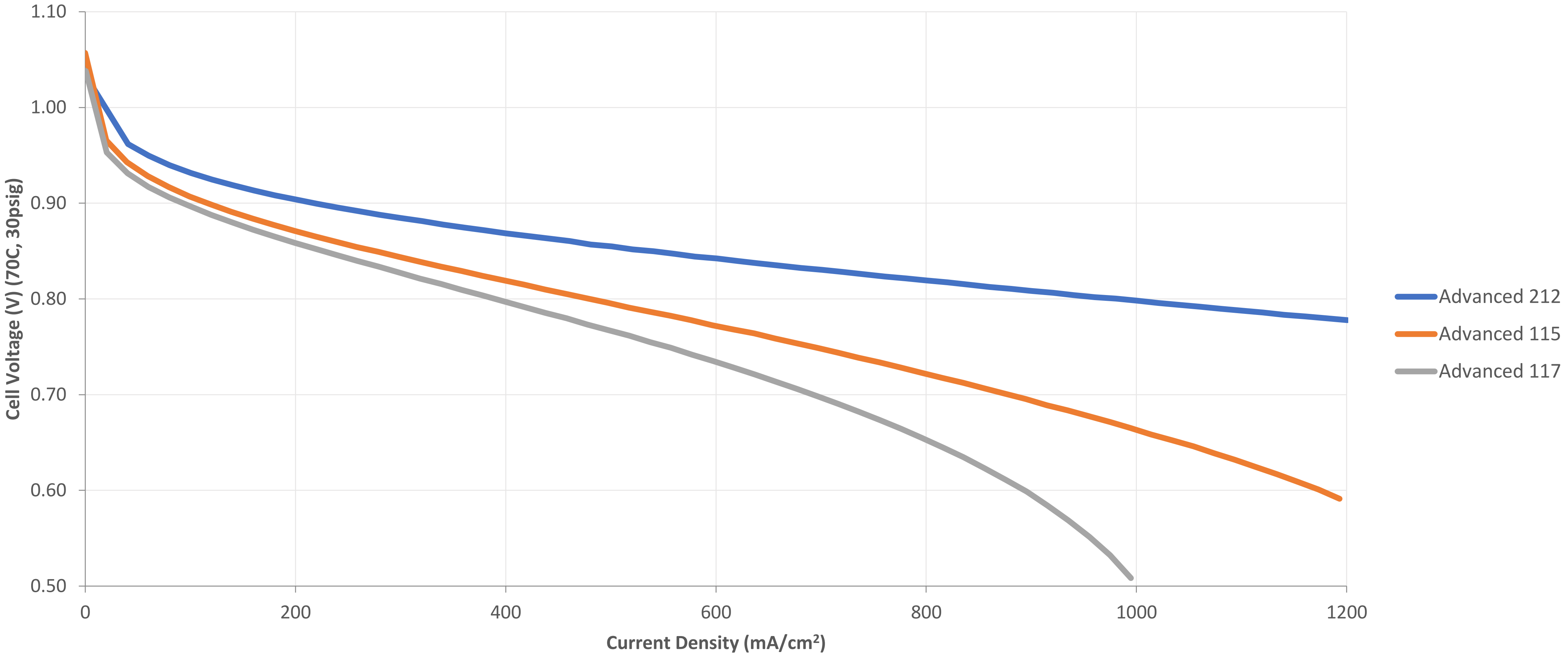
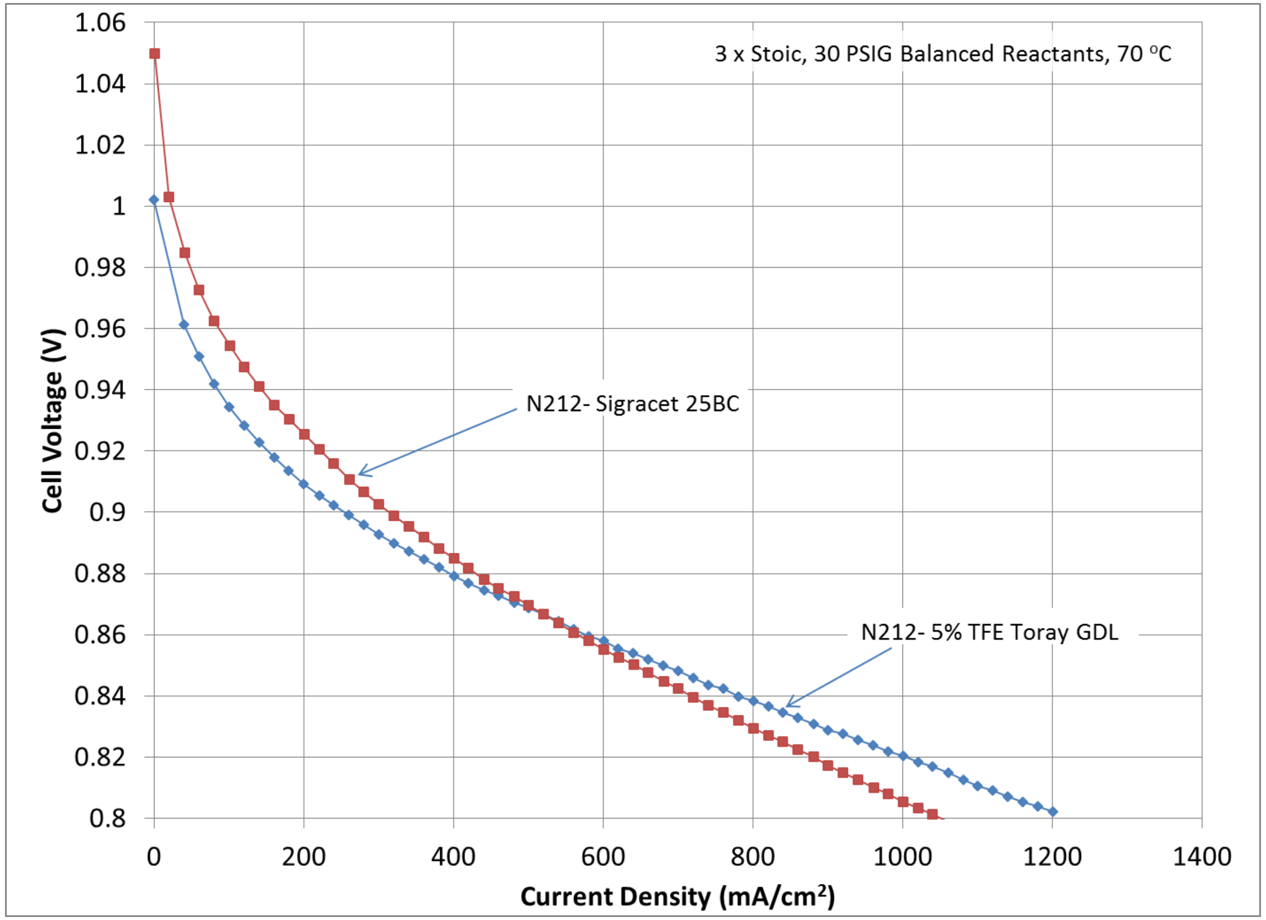
High Performance Fuel Cell Concepts

Membrane thickness – mass transfer resistance vs mechanical properties



High Performance Fuel Cell Concepts

High catalyst loading and gas diffusion layer optimization

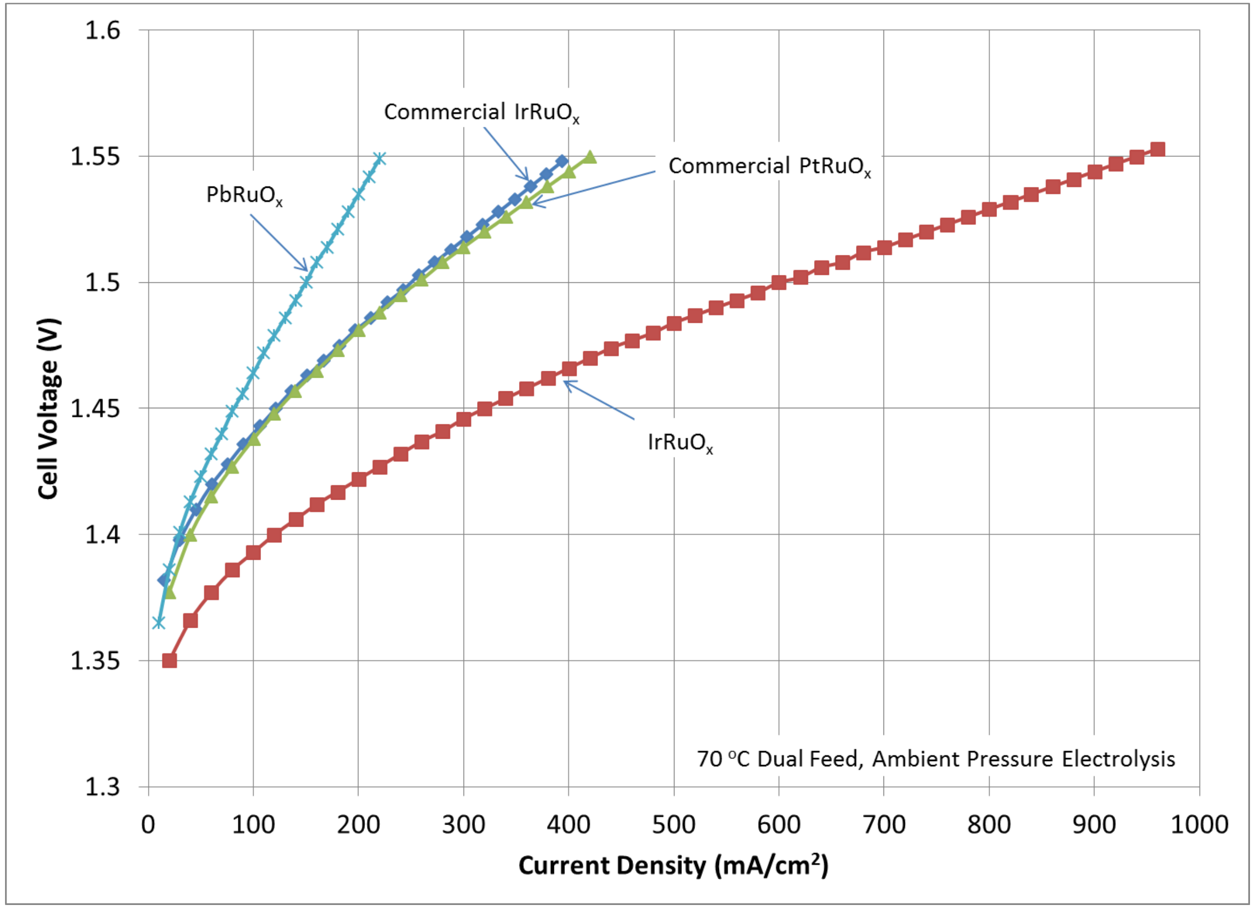


Microporous layer (MPL) coated carbon felt gives preferable performance at target current densities relative to carbon paper

75% Voltage efficiency at 200mA/cm2

High Performance Electrolysis Concepts

Advanced catalyst – Irridium-doped ruthenium oxide

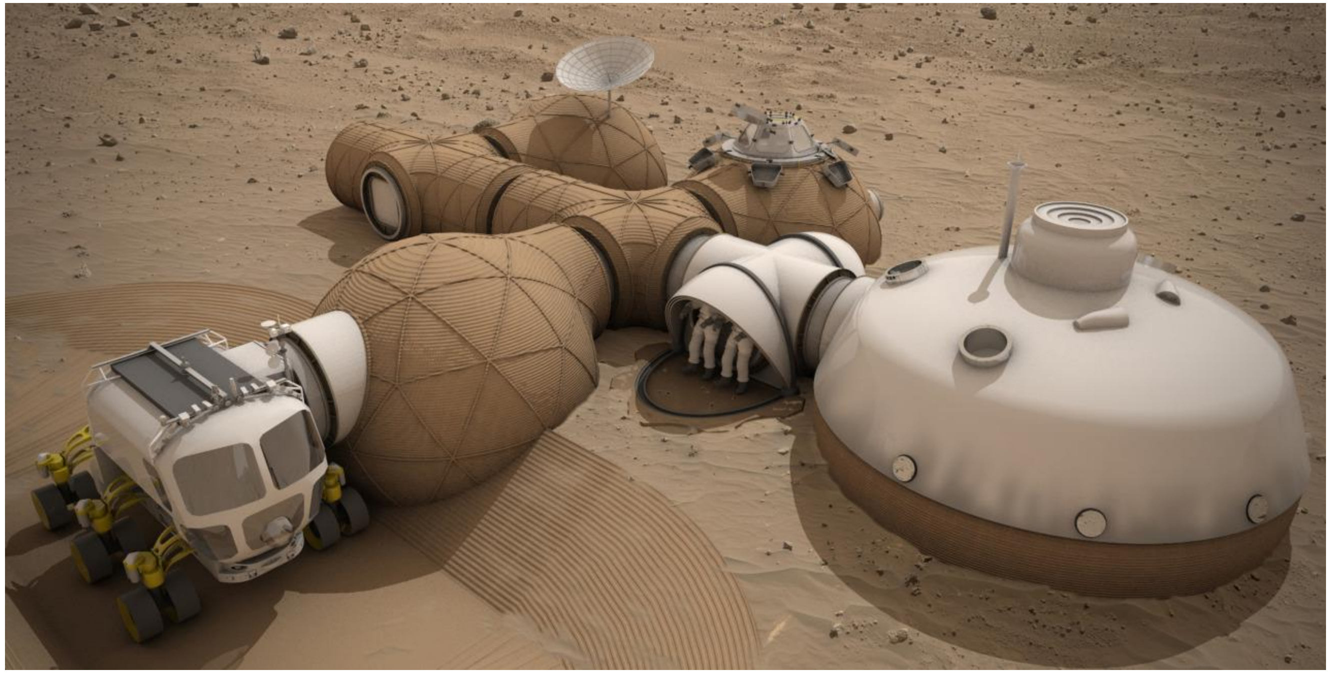


Dope ruthenium oxide with iridium to stabilize the III oxidation state

85% Voltage efficiency at 200mA/cm2

Regenerative fuel cell design for Mars applications

- Support habitats, mobility systems, ISRU
- Work in tandem with solar or nuclear energy sources



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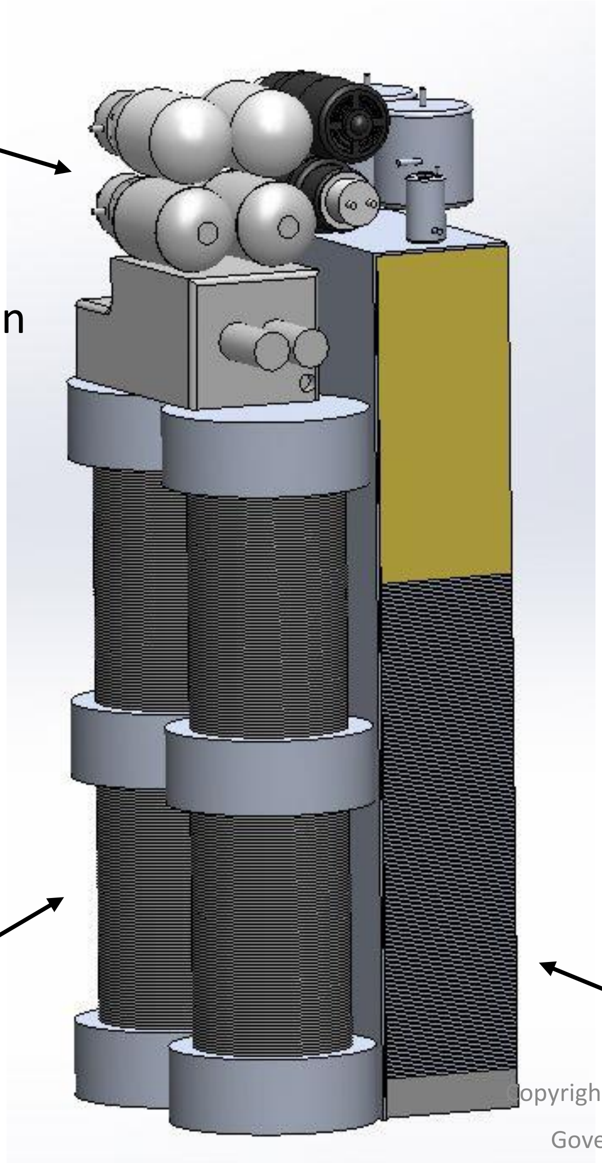
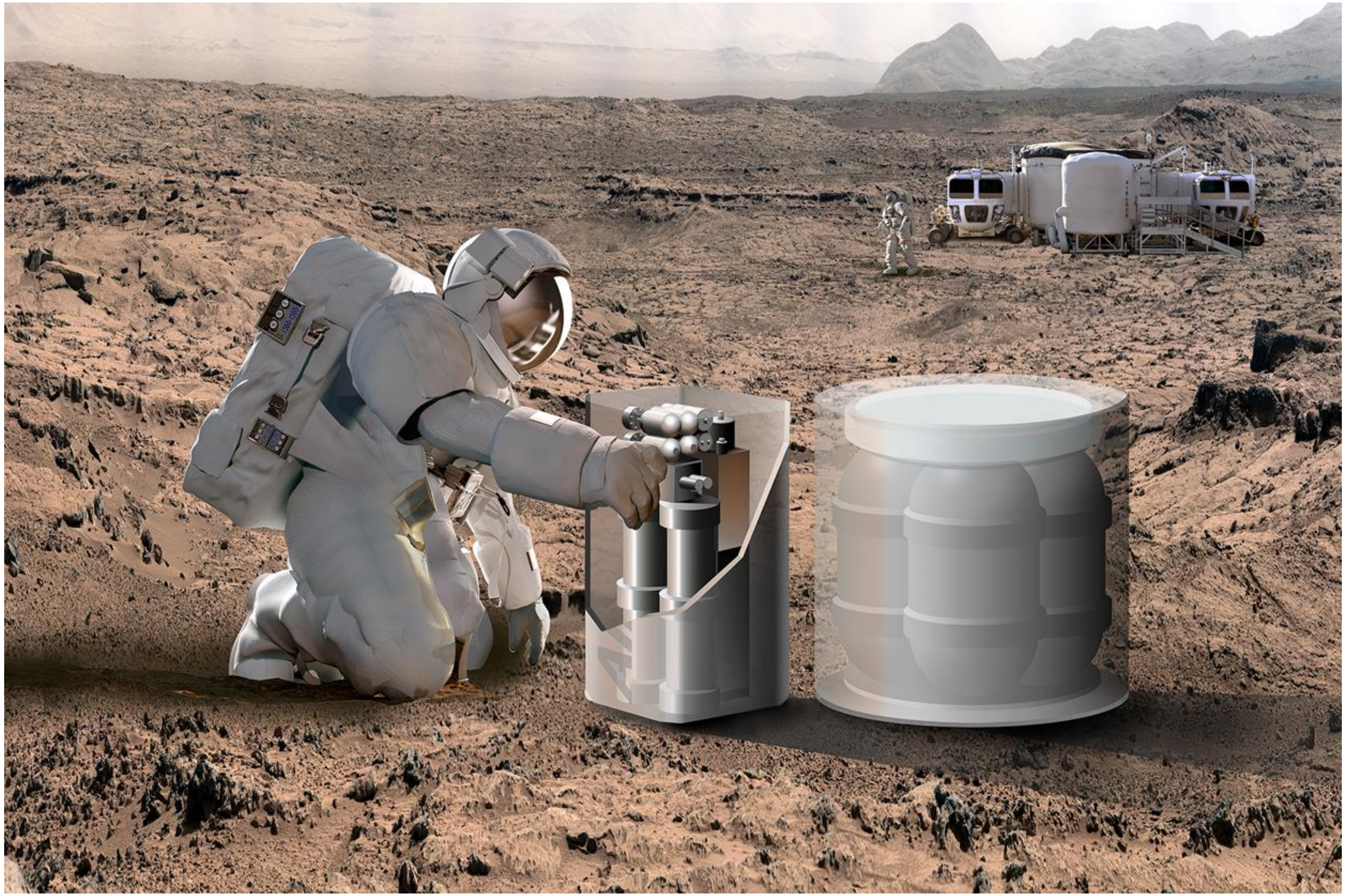
Regenerative fuel cell system design (AIRS)



Combine elements to create a mass-efficient energy storage system

- Fuel cell stack
- High pressure electrolysis cell stack
- Reactant storage
- Reactant management/balance of plant

Modular system design



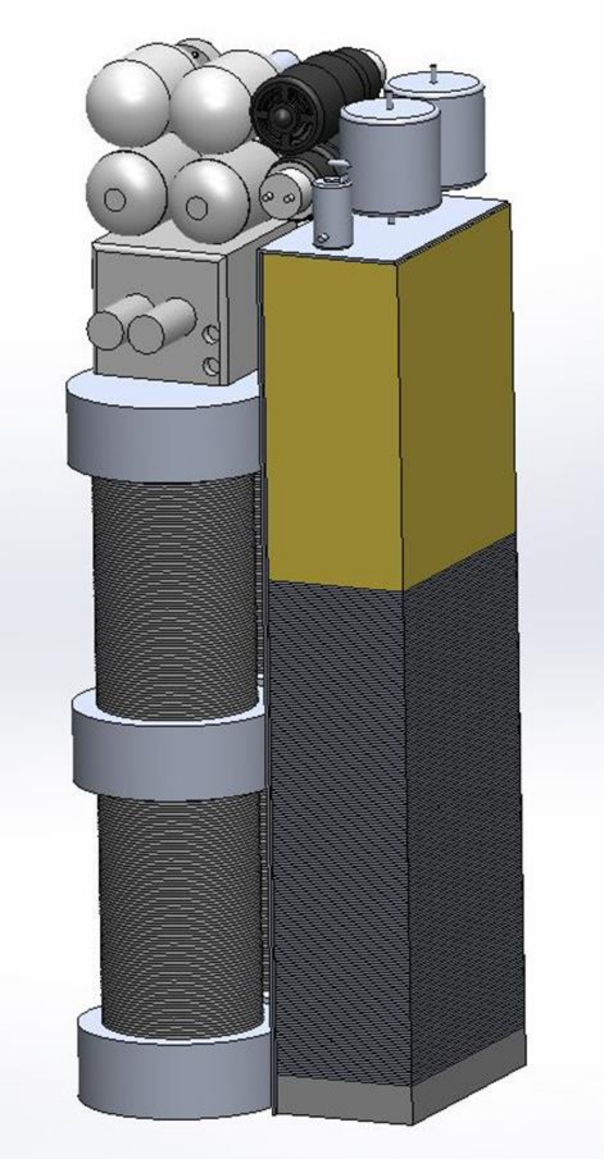
AIRS Regenerative System Design Stats

AIRS Energy Storage System

- 55% Round trip electrical power efficiency
  - Output Power: 10 kW
  - Up to 2kW heating power for habitat, electronics
    - 90% efficiency when accounting for heat use
  - Recharge Power: 18.3 kW

- Teledyne Energy Systems, Passive Flow-Through Stack Technology
- Proton Onsite 3600 PSIG electrolyzer with common endplate design

- System Energy Density:
  - > 360 Wh/kg @ 120 kWh storage (24 hr cycle)
  - ~ 850 Wh/kg @ 3,600 kWh storage (30 day cycle)



Summary

- Regenerative fuel cell systems offer high specific energy storage for space applications, with opportunities for integration with life support

- Efficiency >90% is achievable with the application of waste heat

- Small changes in cell design have system-level consequences

Government sponsorship acknowledged.

Acknowledgements

The work presented here was carried out at the Jet Propulsion Laboratory, California Institute of Technology for the National Aeronautics and Space Administration.